APPLICATION UNDER UNITED STATES PATENT LAWS

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Invention: PHASE-CHANGE OPTICAL RECORDING MEDIUM

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This is a:

☐ Provisional Application

☒ Regular Utility Application

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☐ PCT National Phase Application

☐ Design Application

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SPECIFICATION

TITLE OF THE INVENTION

PHASE-CHANGE OPTICAL RECORDING MEDIUM

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the

5   benefit of priority from the prior Japanese Patent

Applications No. 2002-339437, filed November 22, 2002;

and No. 2002-342896, filed November 26, 2002, the

entire contents of both of which are incorporated

herein by reference.

10   BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a phase-change

optical recording medium in which phase change between

a crystalline phase and an amorphous phase is

15   reversibly caused by irradiation with a light beam so

as to record information.

2. Description of the Related Art

(Principle of Phase-Change Optical Recording Medium)

The phase-change optical recording medium,

20   comprising a phase-change optical recording film that

permits reversible phase change between a crystalline

phase and an amorphous phase upon irradiation with

a light beam, is operated by the principle described in

the following. In a write stage, a region irradiated

25   with a light beam is heated to a temperature higher

than the melting point thereof so as to be melted,

followed by rapidly cooling the region to change

the arrangement of the atoms in the region into an amorphous phase. In the erasing stage, a temperature in a region irradiated with a light beam is maintained for at least a prescribed period of time to fall within a temperature range from the crystallization temperature to the melting point. Then, where the initial state is crystalline, the crystalline phase is left unchanged. On the other hand, where the initial state is amorphous, the amorphous phase is crystallized. In a reading stage, utilizing the fact that the intensity of reflected light from the amorphous region differs from the intensity of reflected light from the crystalline region, the intensity changes of reflected light are converted into electric signals, and then the converted electric signals are subjected to analog-to-digital conversion so as to read out recorded information.

Incidentally, it is also possible to carry out read/write of information by utilizing a transition between a metastable crystalline phase such as a martensite phase and a stable crystalline phase or a transition between metastable crystalline phases, in addition to the phase change between the crystalline phase and the amorphous phase.

(Approaches to Improve Recording Density)

For increasing an amount of information that can be recorded in a single recording medium, i.e.,

for increasing recording capacity, it is conceivable to improve recording density by the two methods given below.

One method for improving the recording density is to reduce a pitch of the recording marks in the track direction. However, if the degree of size reduction proceeds, a region in which the pitch of the recording marks is made smaller than the size of the read beam is arrived at, with the result that it is possible for two recording marks to be included temporality in the read beam spot. Where the recording marks are sufficiently apart from each other, the read signals can be greatly modulated so as to make it possible to obtain signals having high amplitude. However, where the recording marks are positioned close to each other, signals having low amplitude are obtained, with the result that errors tend to be generated when the obtained signals are converted into the digital data.

The other method of improving the recording density is to reduce a track pitch. In this method, it is possible to increase the recording density while avoiding significant influence given by degradation in signal intensity caused by the reduction in the mark pitch noted above. However, this method gives rise to a problem of a so-called "cross-erase" that, in a region in which the track pitch is substantially equal to or smaller than the size of the light beam,

data on a certain track is degraded while the adjacent track is undergoing writing or erasing.

The cross-erase is caused by the phenomenon that the recording mark is irradiated directly with the periphery of a laser beam on the adjacent track, and the phenomenon that the heat flow in the write stage flows into the adjacent track so as to elevate the mark temperature and, thus, to degrade the shape of the mark. It is necessary to overcome these problems for increasing the recording density of the phase-change optical recording medium.

(Approach to Achieve High-Speed Recording)

High-speed recording is another requirement for the phase-change optical recording medium. For example, where video signals can be recorded in a time shorter than an actual viewing time, it is possible to realize easily a so-called "time-shift function" which is referred to as a function of viewing previous scenes in dubbing a distributed recording medium or in recording a broadcasting program. One of the factors for inhibiting the high-speed recording in the phase-change optical recording is the problem that the data fails to be erased completely when the crystallization is performed by a laser beam having an erase level of a relatively low power in the overwriting stage, i.e., the problem of an insufficient erasure rate. Since a recording mark passes through a laser spot at high

speed, the temperature of the recording mark fails to
be maintained for a sufficiently long time to fall
within a range within which crystallization can be
achieved, with the result that the data fails to be
5   erased completely.

An idea of arranging a GeN-based interface film in
contact with a phase-change optical recording film for
accelerating crystallization so as to increase the
erasure rate is disclosed in "Acceleration of
10   crystallization process by nitride interface layer",
Proceedings of The 10th Symposium on Phase Change
Optical Information Storage, pp. 85-89, and in Japanese
Patent Application KOKAI Publication No. 11-213446.
However, according to the experiments conducted by
15   the present inventors, it has been found that, in
the phase-change optical recording medium having
a GeN-based interface layer, a problem is generated in
the write stage. The problem is based on the
phenomenon that the peripheral portion of an initially
20   melted region Im in the write stage is recrystallized,
and an amorphous recording mark M is formed inside the
recrystallized peripheral portion, as shown in FIG. 1.
To be more specific, since it is necessary to melt
a larger region in order to form a recording mark of
25   a desired size, the cross-erase is to be promoted, with
is a reverse effect in view of high-density recording.
On the other hand, if the writing is performed with

a laser power that is allowable in terms of the cross-erase, a problem is generated that the width of the recording mark to be formed is reduced so as to lower a carrier-to-noise ratio (CNR).

5   Such being the situation, it has been desired to develop a novel material for the interface film, which permits increased crystallization speed in erasing so as to overcome the problem in terms of the insufficient erasure rate and which also makes it possible to

10   suppress the recrystallization of the melted region in writing.

(Increase in Recording Capacity by Dual-Layer Medium)

As another method for increasing the recording capacity, a method of superposing a plurality of

15   information layers each containing a phase-change optical recording film is known. The particular method is disclosed in, for example, Japanese Patent Application KOKAI Publication No. 2000-322770. It should be noted that it is necessary for the first

20   information layer positioned close to the light incident side to ensure at least about 50% of transmittance in order to prevent the light from being superfluously attenuated in accessing to the second information layer positioned remote from the light

25   incident side. To this end, it is necessary to reduce the thickness of the recording film to about 5 to 8 nm. Since the thickness of the recording film is much

reduced, the retention time required for the crystallization is made long, with the result that the recorded information fails to be erased completely in ordinary high-speed recording.

5   As a measure for overcoming the difficulty, it is disclosed that a method of substituting Sn for a part of the GeSbTe recording film is effective, in Proceedings of The 12th Symposium on Phase-change Optical Information Storage PCOS 2000, pp. 36-41.

10   Also, it is disclosed that a method of substituting Bi, In, Sn or Pb for a part of the GeSbTe recording film is effective, in Japanese Patent Application KOKAI Publication No. 2001-232941.

    Where the thickness of the recording film exceeds
15   15 nm, a temperature difference is generated between the upper portion of the recording film positioned closer to the reflection film and cooled at a high rate and the lower portion of the recording film. Therefore, crystal nuclei are generated on the upper
20   portion of the recording film and the crystal nuclei grow so as to cause the entire recording film to be crystallized. However, where the thickness of the recording film is small, a sufficient temperature difference is not generated between the upper and lower
25   portions of the recording film. Thus, for compensating the crystallization speed that has been lowered in accordance with the reduction in the thickness of

the recording film, it is insufficient to adjust

the composition of the recording film material, and it

is necessary to arrange a film producing the effect of

accelerating crystallization at the interface with the

5   recording film. According to the Proceedings of The

12th Symposium on Phase change Optical Information

Storage, it is effective to arrange, for example, a GeN

interface film. However, it has been found as a result

of research conducted by the present inventors that, in

10   the combination of a thin recording film having a

thickness of about 5 to 8 nm and a conventional

interface film such as the GeN film, the cross-erase is

generated to degrade read signal characteristics, with

the result that errors are generated frequently in

15   converting the read signals into digital data.

Particularly, the signal characteristics are

prominently degraded in the case where the thickness of

the GeN interface film is smaller than about 5 nm.

On the other hand, the reflection film serves to

20   cool the recording film that has been heated by the

absorption of the recording light. However, since it

is necessary to decrease the thickness of the

reflection film in the semi-transparent information

layer (the first information layer), the cooling

25   function of the reflection film becomes insufficient,

with the result that the read signal characteristics

are degraded. As a measure against the difficulty,

an idea of forming a heat sink film on the reflection film is disclosed in, for example, Japanese Patent Application KOKAI Publication No. 2000-222777. Also, it is reported that signal characteristics are improved in the case of arranging a heat sink film having a thickness of about 100 nm and made of AlN having very high heat conductivity, in Proceedings of ISOM/ODS 2002, pp. 234-236. However, it has been found as a result of research conducted by the present inventors that recording sensitivity is degraded in the case of using a material having very high heat conductivity such as AlN for a heat sink film.

As described above, in the first information layer (semi-transparent information layer) of the dual-layer single-sided phase-change optical recording medium, it is necessary to make both of the recording film and the reflection film thinner than those of the ordinary medium. Such being the situation, it has been desired to develop an interface film permitting a high CNR and an erasure rate while maintaining the cross-erase to a low level and to optimize the thermal characteristics of the medium including those of the interface film and the heat sink film.

BRIEF SUMMARY OF THE INVENTION

An object of the present invention is to provide a phase-change optical recording medium, which makes it possible to ensure a sufficiently high CNR by

suppressing cross-erase, and which also permits high-speed overwriting with a high recording density and a high capacity.

A phase-change optical recording medium according to an aspect of the present invention comprises: a phase-change optical recording film that permits reversible phase change between a crystalline phase and an amorphous phase upon irradiation with light; and an interface film formed of hafnium oxide, or a mixture of hafnium oxide and at least one oxide selected from the group consisting of cerium oxide, titanium oxide and zirconium oxide, and formed in contact with at least one surface of the phase-change optical recording film.

A phase-change optical recording medium according to another aspect of the present invention comprises: a semi-transparent, first information layer comprising a phase-change optical recording film, an interface film formed of at least one oxide selected from the group consisting of hafnium oxide and cerium oxide and formed in contact with at least one surface of the phase-change optical recording film, a semi-transparent reflection film, and a heat sink film; a second information layer; and a resin layer formed between the first information layer and the second information layer, in which heat conductivity of the heat sink film is at least 0.7 times as high as that of the interface film and not higher than 100 W/mK.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. 1 shows an amorphous mark in a conventional phase-change optical recording medium;

FIG. 2 shows an amorphous mark in a phase-change optical recording medium according to an embodiment of the present invention;

FIG. 3 is a cross-sectional view showing the stacked structure of a phase-change optical recording medium according to one embodiment of the present invention;

FIG. 4 is a cross-sectional view showing the stacked structure of a phase-change optical recording medium according to another embodiment of the present invention;

FIG. 5 is a cross-sectional view showing the stacked structure of a phase-change optical recording medium according to another embodiment of the present invention;

FIG. 6 is a cross-sectional view showing the stacked structure of a dual-layer single-sided recording medium according to another embodiment of the present invention;

FIG. 7 is a cross-sectional view showing the stacked structure of a dual-layer single-sided recording medium according to still another embodiment of the present invention;

FIG. 8 is a cross-sectional view showing

the stacked structure of a dual-layer single-sided phase-change optical recording medium according to still another embodiment of the present invention;

FIGS. 9A and 9B schematically show how heat conduction is carried out from a recording film included in a semi-transparent information layer, respectively;

FIGS. 10A and 10B show combinations of a thickness of a second interference film and a thickness of a heat sink film which brings about satisfactory optical characteristics for a semi-transparent information layer, where a refractive index of the heat sink film is 1.8 and 2.7, respectively;

FIGS. 11A and 11B show optical characteristics of a semi-transparent information layer as a function of a refractive index and a thickness of a heat sink film, where a refractive index of UV curable resin used for bonding the information layers is 1.52 and 1.80, respectively;

FIGS. 12A and 12B show optical characteristics of a semi-transparent information layer, including an interface film of HfO_2 and a heat sink film of SiO_2 and TiO_2, respectively, as a function of a thickness of a first interference film and a thickness of a second interference film; and

FIGS. 13A and 13B show optical characteristics of a semi-transparent information layer, including

an interface film of CeO_2 and a heat sink film of SiO_2 and TiO_2, respectively, as a function of a thickness of a first interference film and a thickness of a second interference film.

DETAILED DESCRIPTION OF THE INVENTION

The phase-change optical recording medium according to the embodiments of the present invention will now be described more in detail. The phase-change optical recording medium according to the embodiments of the present invention includes an interface film formed on at least one surface of the phase-change optical recording film and containing hafnium oxide or cerium oxide. Incidentally, the expression "formed in contact with the phase-change optical recording film" is used unless a film not containing hafnium oxide or cerium oxide is formed intentionally between the phase-change optical recording film and the interface film. For example, even where a very thin oxide film having a thickness of 2 nm or less, which is naturally formed on the surface of the phase-change optical recording film during the deposition process, has been detected by, for example, Auger analysis, the interface film is regarded as being formed in contact with the phase-change optical recording film.

Since the phase-change optical recording medium according to the embodiments of the present invention has the interface film containing hafnium oxide or

cerium oxide formed in contact with a phase-change optical recording film, it is possible to make the size of a recording mark M substantially equal to the size of an initially melted region in the write stage, as

5   shown in FIG. 2.

FIG. 3 is a cross-sectional view showing a stacked structure of a phase-change optical recording medium according to one embodiment of the present invention. In the phase-change optical recording medium shown in

10   FIG. 3, the first interference film 11, the lower interface film 12, the phase-change optical recording film 13, the upper interface film 14, the second interference film 15 and the reflection film 16 are stacked successively in the order mentioned on the

15   substrate 1.

Incidentally, FIG. 3 shows the basic structure of the phase-change optical recording medium of the present invention. However, the structure of the phase-change optical recording medium of the present

20   invention is not limited to the structure shown in FIG. 3. For example, in the phase-change optical recording medium shown in FIG. 3, the interface films 12, 14 are formed in contact with the both surfaces of the phase-change optical recording film 13. However,

25   it suffices for the interface film to be formed in contact with at least one surface of the phase-change optical recording film 13. Also, it is possible to

form another dielectric film between the second interference film 15 and the reflection film 16 or to use a plurality of films for forming the reflection film 16. Further, various modifications are

5 conceivable as described herein later in detail.

The recording film 13 in the phase-change optical recording medium is irradiated with light passing through the substrate 1. In many cases, the phase-change optical recording medium is designed to permit

10 the reflectance (Ra) of the amorphous portion and the reflectance (Rc) of the crystalline portion to have a relationship of Ra < Rc, though it is possible to design the phase-change optical recording medium to have a relationship of Ra > Rc, as described herein

15 later.

Hafnium oxide contained in the interface film is expressed as HfO_2 in terms of the stoichiometric composition. However, it suffices for the hafnium oxide used in the embodiments of the present invention

20 to have a composition represented by the formula HfO_x, where $1.8 \leqq x \leqq 2.2$.

The present inventors have conducted extensive research using known interface film materials effective for accelerating crystallization of the recording film

25 such as germanium nitride (GeN), silicon carbide (Si-C) and silicon nitride (Si-N). It has been found that there is a trade-off relationship that a CNR is lowered

in the case of using a material having a high effect of
accelerating the crystallization and a material
that permits a high CNR is poor in the effect of
accelerating the crystallization. On the other hand,
it has been found that, in the case of using hafnium
oxide for the interface film, it is possible to obtain
a high CNR and a high effect of accelerating the
crystallization.

It has been found that the effect similar to that
described above can also be obtained in the case of
using a mixture comprising hafnium oxide and at least
one oxide selected from the group consisting of cerium
oxide (CeO_2), titanium oxide (TiO_2) and zirconium oxide
(ZrO_2) for the interface film. In the case of mixing
hafnium oxide with an oxide of the divalent metal, it
is possible to obtain a high CNR and a high effect of
accelerating the crystallization. On the other hand,
when it comes to the combination of hafnium oxide and
an oxide of a pentavalent metal such as Ta_2O_5 or Nb_2O_5
or an oxide of a trivalent metal such as Mo_2O_3 or
Cr_2O_3, it is impossible to achieve both a high CNR and
a high effect of accelerating the crystallization.
The mechanism that the combination of hafnium oxide
and an oxide of a divalent metal can produce the
particularly prominent effects as described above has
not yet been clarified sufficiently. However, the
reason for the above result is probably due to the fact

that the bonding between the divalent metal and oxygen is stronger than the bonding between the pentavalent metal or the trivalent metal and oxygen.

In the case of using an interface film formed of a mixture comprising hafnium oxide and at least one oxide selected from the group consisting of cerium oxide, titanium oxide and zirconium oxide, it is possible to control easily the refractive index and/or the heat conductivity characteristics of the interface film while maintaining a satisfactory function of accelerating the crystallization.

The recording film included in the phase-change optical recording medium absorbs light so as to be heated, and the heat is transmitted through the upper and lower films so as to cause the recording film to be cooled. The degree of heating and cooling of the recording film is changed in accordance with not only factors such as a light output, a linear velocity of the recording medium, an irradiating time with light and a crystallization speed of the recording film but also heat conductivity characteristics of the films formed on the upper and lower sides of the recording film, which determines whether the recording film is rendered amorphous or crystalline. It follows that, in order to form satisfactory recording marks on the recording film and to obtain sufficient erasure characteristics of the recording film at a desired

linear velocity, it is desirable to control
appropriately the heat conductivity of each of the
films formed on the upper and lower sides of the
recording film.

5   When it comes to the interface film formed of the
oxide mixture referred to above, the refractive index
and/or the heat conductivity characteristics can be
controlled in accordance with the types and the mixing
ratio of the oxide materials which are to be mixed,

10   with the result that the design of the film
construction of the recording medium can be markedly
facilitated. As a result, it is possible to employ
a stacked structure in which the interference film
(also called a protective film) made of $ZnS:SiO_2$, i.e.,

15   a mixture of ZnS and SiO_2, is omitted, although it has
been considered to be indispensable in the conventional
phase-change optical recording medium. In the phase-
change optical recording medium having the particular
stacked structure, it is possible to decrease the total

20   number of films (or the number of deposition processes)
by the number of the interference film to be omitted,
which improves productivity.

       FIGS. 4 and 5 are cross-sectional views each
showing a stacked structure of the phase-change optical

25   recording medium according to another embodiment of the
present invention. In each of these phase-change
optical recording media, at least one interference film

is omitted from the stacked structure shown in FIG. 3.

The phase-change optical recording medium shown in FIG. 4 has a structure that the first interference film 11, the lower interface film 12, the phase-change optical recording film 13, the upper interface film 14 and the reflection film 16 are stacked in the order mentioned on the substrate 1. In the phase-change optical recording medium shown in FIG. 4, the interference film on the side of the reflection film 16 relative to the recording film 13 is omitted from the stacked structure shown in FIG. 3.

The phase-change optical recording medium shown in FIG. 5 has a structure that the lower interface film 12, the recording film 13, the upper interface film 14 and the reflection film 16 are stacked in the order mentioned on the substrate 1. In the phase-change optical recording medium shown in FIG. 5, the interference films on the light incident side and on the side of the reflection film 16 relative to the recording film 13 are omitted from the stacked structure shown in FIG. 3.

In the embodiments of the present invention, it is desirable to use, for example, GeSbTe for the phase-change optical recording film. In particularly, a prominent effect can be obtained in the case of using the interface film specified in the present invention in combination with a GeSbTe phase-change optical

recording film having a composition close to

a so-called pseudo-binary system, which can be

represented by $(GeTe)_a(Sb_2Te_3)_b$, preferably a GeSbTe

phase-change optical recording film having

5   a composition close to the pseudo-binary system and

containing Ge in an amount of at least 20 atomic %, and

more preferably a GeSbTe phase-change optical recording

film having a composition close to the pseudo-binary

system and containing Ge in an amount of at least

10   30 atomic %.

To be more specific, when a material used for

the phase-change optical recording film is represented

by the general formula $Ge_xSb_yTe_z$, where x+y+z = 100, it

is desirable to use a composition falling within a

15   range defined by x = 55 and z = 45; x = 45 and z = 55;

x = 20, y = 20 and z = 60; and x = 20, y = 28 and

z = 52 in the GeSbTe ternary phase diagram.

It is more desirable to use a composition falling

within a range defined by x = 55 and z = 45; x = 45 and

20   z = 55; x = 25, y = 16 and z = 59; and x = 25, y = 24

and z = 51 in the GeSbTe ternary phase diagram.

Also, for the phase-change optical recording film,

it is possible to use a material having Bi and/or Sn

substituted for a part of the GeSbTe material of the

25   composition range described above. The material

referred to above is represented by the general

formula, $(Ge_wSn_{(1-w)})_x(Sb_yBi_{(1-y)})_yTe_z$, where

x+y+z = 100, $0 \leqq w < 0.5$ and $0 \leqq v < 0.7$. If the substitution ratio w of Sn for Ge is not lower than 0.5, the crystallization speed is rendered excessively high so as to cause the recrystallization after melting to be prominent, resulting in failure to form amorphous marks stably. Also, if the substitution ratio v of Bi for Sb is not lower than 0.7, the crystallization speed is also rendered excessively high so as to cause the recrystallization after melting to be prominent, resulting in failure to form amorphous marks stably.

Further, it is possible to use a recording film material prepared by adding traces of elements, e.g., Co, V and Ag, other than Sn and Bi, to GeSbTe such that the effect of the present invention is not impaired.

In the embodiments of the present invention, as a material for the first and second interference films, a dielectric material or a mixture thereof, which is substantially transparent and has appropriate heat conductivity, may be used. To be more specific, the material for the interference films includes, for example, $ZnS-SiO_2$, SiO_2, SiO, Si-O-N, Si-N, Al_2O_3, Al-O-N, TiO_2, Ta-N, Ta_2O_5, Ta-O-N, Zn-O, ZnS, ZrO_2, Zr-O-N, Zr-N, Cr-O, Mo-O, W-O, V-O, Nb-O, Ta-O, In-O, Cu-O, Sn-O and In-Sn-O.

Also, it is possible to design a phase-change optical recording medium of a so-called "Low-to-High" polarity, in which the reflectance of the amorphous

portion is higher than the reflectance of the
crystalline portion, by allowing the interference film
on the light incident side to be formed of a stacked
structure consisting of a plurality of interference

5   films. For example, it is possible to realize the
Low-to-High polarity by allowing the interference film
on the light incident side to be of a three-layered
structure of $ZnS:SiO_2/SiO_2/ZnS:SiO_2$ or of a two-layered
structure of $ZnS:SiO_2/SiO_2$ and by designing

10   appropriately the thickness of each film.

The appropriate thickness of each layer included
in the phase-change optical recording medium shown in
each of FIGS. 3 to 5 will now be described.

In order to design the phase-change optical

15   recording medium as shown in FIG. 3 such that the
reflectance (Ra) of the amorphous portion is rendered
lower than the reflectance (Rc) of the crystalline
portion, it is desirable for the total thickness of the
first interference film 11 and the lower interface film

20   12 on the light incident side to fall within a range of
between 30 nm and 200 nm, for the thickness of the
phase-change optical recording film 13 to be 20 nm or
less, for the total thickness of the upper interface
film 14 and the second interference film 15 on the side

25   of the reflection film to be 5 nm or more, and for
the thickness of the reflection film 16 to fall within
a range of between 30 nm and 400 nm. If the thickness

of the phase-change optical recording film 13 exceeds
20 nm, the cross-erase tends to take place easily.

The thicknesses of the films described above can
also be applied to the cases where the interference
film is omitted from the stacked structure consisting
of the interference film and the interface film into
the interface film alone as shown in FIGS. 4 and 5.
Where the interference film is not formed on the light
incident side, it is desirable for the lower interface
film 12 to have a thickness falling within a range of
between 30 nm and 200 nm. Where the interference film
is not formed on the side of the reflection film, it is
desirable for the upper interface film 14 to have
a thickness of 5 nm or more.

Also, in the case of using a stack of a plurality
of dielectric films for a phase-change optical
recording medium of the Low-to-High polarity (Ra > Rc)
as described above, it is desirable to determine the
thickness of each dielectric film in a manner to
satisfy desired reflectance under the condition that
the total thickness of the plural interference films
and the lower interface film 12 to fall within a range
of between 30 nm and 200 nm.

It is possible for the phase-change optical
recording medium according to another embodiments of
the present invention to be a dual-layer single-sided
recording medium having two phase-change optical

recording films capable of independently writing, erasing and reading data by irradiation with light incident on one side.

FIG. 6 is a cross-sectional view showing the stacked structure of a phase-change optical recording medium (dual-layer single-sided recording medium) according to another embodiments of the present invention. The phase-change optical recording medium shown in FIG. 6 having a structure in which the first substrate 1 having the first information layer 10 formed thereon and the second substrate 2 having the second information layer 20 formed thereon are bonded to each other such that the first and second information layers 10 and 20 are allowed to face each other with the UV curable resin layer 30 interposed between them. It is possible to employ the stacked structure as shown in, for example, FIGS. 3 to 5 for each of the first and second information layers 10 and 20. Incidentally, prominent effects can be obtained by simply arranging the interface film in contact with the recording film included in the first information layer 10 positioned on the light incident side.

FIG. 7 shows an example of a stacked structure of a first information layer. The first information layer shown in FIG. 7 has a structure that the first interference film 11, the lower interface film 12,

the phase-change optical recording film 13, the upper

interface film 14, the second interference film 15, the

reflection film 16 and the heat sink film 17 are

arranged on the substrate 1.

5   FIG. 8 shows a dual-layer single-sided phase-

change optical recording medium according to one

embodiment of the present invention. As shown in

the drawing, on the first substrate 1, the first

interference film 11, the lower interface film 12, the

10   phase-change optical recording film 13, the upper

interface film 14, the second interface film 15, the

semi-transparent reflection film 16, and the heat sink

film 17, are deposited successively so as to form the

first information layer (semi-transparent information

15   layer) 10. In addition, on the second substrate 2, the

reflection film 24, the second interference film 23,

the phase-change optical recording film 22, and the

first interference film 21 are deposited successively

so as to form the second information layer 20. The

20   first substrate 1 and the second substrate 2 are

arranged in a manner that the first and second

information layers to face each other are bonded with

a UV curable resin layer 30 interposed between them.

The recording films are irradiated with light incident

25   on the first substrate 1.

Incidentally, the structure of the dual-layer

single-sided optical recording medium is not limited to

that shown in FIG. 8. For example, it is possible to form a plurality of dielectric films between the first substrate 1 and the lower interface film 12. It is also possible to omit the first interference film 11 and the second interference film 15 and to form the upper interface film 14 alone between the phase-change optical recording film 13 and the reflection film 16. Further, it is possible for the reflection film 16 to be formed of a plurality of films.

In the dual-layer single-sided optical recording medium, writing, erasing and reading for the first information layer 10 are carried out by the light transmitted through the first substrate 1, and writing, erasing and reading for the second information layer 20 are carried out by the light transmitted through the first information layer 10. Therefore, the first information layer on the light incident side is rendered semi-transparent to the recording light. The expression that the first information layer is semi-transparent means herein that the transmittance for the recording light is 40 to 70% in the first information layer. In order to make the first information layer semi-transparent, it is desirable for the recording film to have a thickness of 5 to 8 nm and for the reflection film to have a thickness of 5 to 10 nm.

As described above, in order to increase the transmittance of the first information layer 10, it is

effective to decrease the thickness of each of the recording film and the reflection film. If the thickness of each of these films is decreased, however, the cooling effect is lowered. As a result,

5 recrystallization of the melted region is rendered prominent in writing so as to give rise possibly to the inconvenience that it is difficult to perform the writing at an ordinary linear velocity. Such being the situation, for the first information layer 10, it is

10 desirable to employ the stacked structure capable of making up for the decrease of the cooling effect.

In the first information layer of the dual-layer single-sided medium, it is desirable for the total thickness of the first interference film 11 and the

15 lower interface film 12 on the light incident side to fall within a range a between 30 nm and 200 nm, for the thickness of the phase-change optical recording film 13 to be 8 nm or less, for the total thickness of the upper interface film 14 and the second interference

20 film 15 on the side of the reflection film to fall within a range of between 5 nm and 100 nm, for the thickness of the reflection film 16 to be 10 nm or less, and for the thickness of the heat sink film 17 to be 100 nm or less.

25 In the first information layer of the dual-layer single-sided medium, it is also possible to employ a stacked structure that an interference film is

omitted as in FIGS. 4 and 5 in which one or two interference films are omitted from the stacked structure shown in FIG. 1. In this case, it is desirable for the lower interface film 12 on the light incident side to have a thickness falling within a range of between 30 nm and 200 and for the upper interface film 14 on the side of the reflection film to have a thickness falling within a range of between 5 nm and 30 nm.

Incidentally, in the first information layer of the dual-layer single-sided medium, it is also possible to omit as required the metal reflection film. In this case, it is desirable to design the refractive index such that it is possible to obtain prescribed reflectance in the interface between, for example, the UV curable resin layer 30 and the interference film in contact with the resin layer 30.

The materials used for the dual-layer single-sided phase-change optical recording medium according to the embodiments of the present invention will now be described.

As described previously, a material containing hafnium oxide or cerium oxide is used for the interface film. Also, the materials noted above are used for the first and second interference films and the phase-change optical recording film.

As a material for the heat sink film, a dielectric

material or a mixture thereof, which is substantially
transparent and has appropriate heat conductivity, is
used. To be more specific, the material for the heat
sink film includes Al_2O_3, SiO_2, SiO, Si-O-N, Si-N,
Al-O-N, TiO_2, Ta-N, Ta_2O_5, Ta-O-N, Zn-O, ZnS, ZrO_2,
Zr-O-N, Zr-N, Cr-O, Mo-O, W-O, V-O, Nb-O, Ta-O, In-O,
Cu-O, Sn-O and In-Sn-O.

The present inventors have conducted recording-
reproducing experiments in respect of phase-change
optical recording media, in which the thickness of the
phase-change optical recording film included in the
first information layer was set at about 6 nm, and
an interface film having a thickness not larger than
5 nm was formed by using materials which are known to
produce the effect of accelerating the crystallization
of the phase-change optical recording film such as
germanium nitride (GeN), chromium oxide (Cr-O), silicon
carbide (Si-C), and silicon nitride (Si-N) as well as
hafnium oxide and cerium oxide.

As a result, it has been found that there is
a trade-off relationship that a CNR is lowered in the
case of using an interface film made of a material
producing the effect of accelerating crystallization
and that the effect of accelerating the crystallization
is rendered poor in the case of using a material that
brings about a high CNR. However, in the case of using
hafnium oxide or cerium oxide for the interface film,

the degree of the trade-off is rendered particularly low so as to make it possible to obtain a high CNR and a high effect of accelerating the crystallization.

The mechanism of producing the particularly prominent characteristics in the case of using hafnium oxide or cerium oxide has not yet been clarified. However, it is considered that the bonding of hafnium or cerium with oxygen is stronger than the bonding of another metal with oxygen so as to produce the particularly prominent characteristics. It was believed in the past that, in the case of using a substance having intense bonding strength and a high hardness for the interface film, the melted recording film is shrunk in the medium including a thick recording film so as to bring about a partial peeling between the recording film and the interface film. On the other hand, the semi-transparent information layer has a thin recording film of 8 nm or less, and the shrinkage of the melted recording film is small and, thus, is unlikely to be peeled off. Therefore, satisfactory characteristics can be exhibited in the case of a semi-transparent information layer even if hafnium oxide or cerium oxide having high hardness is used for the interface film.

It is possible to add another material to the interface film in order to control the refractive index and/or the heat conducting characteristics while

maintaining the satisfactory function of accelerating the crystallization. In the phase-change optical recording medium, the recording film absorbs light so as to generate heat, and the heat thus generated is transmitted into the upper and lower layers so as to be cooled. Whether the recording film is rendered amorphous or crystallized is determined depending on the balance among the power of the irradiating recording light, the heat generation dependent on the linear velocity and the light irradiation time, the heat conductive characteristics of the upper and lower films of the recording film, and the crystallization speed of the recording film. It follows that, in order to form a satisfactory recording mark and to obtain a sufficient erase characteristics at a desired linear velocity, it is important to control accurately the heat conductivity in the upper and lower films of the recording film. In the embodiments of the present invention, it is possible to control the refractive index and the heat conductive characteristics of the interface film by suitably selecting the type and the mixing ratio of the materials mixed with hafnium oxide or cerium oxide, with the result that the design of the structure of the medium can be markedly facilitated. It is also possible to substitute the material of an interface film for the $ZnS:SiO_2$ interference film which was considered to be indispensable in the past.

In this case, it is possible to decrease the number of film deposition processes so as to make it possible to provide a medium excellent in productivity.

The material that can be mixed with hafnium oxide or cerium oxide for the interface film includes, for example, AlN, Al_2O_3, SiO_2, SiO, Si-O-N, Si-N, Al-O-N, Si-C, TiO_2, Ta-N, Ta_2O_5, Ta-O-N, Zn-O, ZnS, ZrO_2, Zr-O-N, Zr-N, Cr-O, Mo-O, W-O, V-O, Nb-O, Ta-O, In-O, Cu-O, Sn-O and In-Sn-O. The interface film may comprise 50 mol% or less of at least one component selected from the above materials. In particular, it is desirable to mix Si-C with hafnium oxide or cerium oxide in order to maintain the mechanical strength of hafnium oxide and cerium oxide.

The present inventors have conducted comparative experiments by using materials having various heat conductivities for the heat sink film. As a result, it has been found that it is desirable for the heat conductivity of the heat sink film to be at least 0.7 times as high as that of the interface film, more preferably, to be higher than that of the interface film, and to be not higher than about 100 W/mK.

FIGS. 9A and 9B schematically show, respectively, how heat conduction is carried out when a recording film included in a semi-transparent information layer is heated by absorption of recording light. Ideally, it is desirable that the heat conduction in the

perpendicular direction from the recording film toward the reflection film and heat sink film be large as shown in FIG. 9A because it is possible in this case to suppress influences given to the recording film in the adjacent tracks. However, where the heat conductivity of the heat sink film is lower than that of the interface film, the heat conduction in the in-plane direction within the interface film is rendered prominent in addition to the heat conduction in the perpendicular direction to the interface film, as shown in FIG. 9B. Since the interface film is in contact with the recording film, if the heat conduction takes place as shown in FIG. 9B, thermal influences may possibly be given to the recording film in the adjacent tracks. In other words, when data are recorded in the present track, the data that have already been recorded in the adjacent tracks are erased so as to cause cross-erase. It follows that, in order to prevent the cross-erase from being generated, the heat conductivity of the heat sink film preferably be higher than that of the interface film.

On the other hand, if the heat conductivity of the heat sink film is excessively high, recording sensitivity of the first information layer (semi-transparent information layer) is lowered. This is because, in the case of performing recording with ordinary light intensity under the condition that

the heat conductivity of the heat sink film is
excessively high, the recording film is made amorphous
in the central portion of the beam where light
intensity is high, while the recording film remains

5   crystalline in the peripheral portion of the beam where
the light intensity is not so high and thus sufficient
melting does not take place. In this case, in order to
make the recording film amorphous in the entire region
of the light beam, it is necessary to carry out

10   recording with light intensity higher than the ordinary
light intensity. It follows that, in order to prevent
the recording sensitivity of the semi-transparent
information layer from being lowered, the heat
conductivity of the heat sink film is required not to

15   be excessively high. It has been clarified as a result
of experiments that it is appropriate for the heat
conductivity of the heat sink film to be not higher
than 100 W/mK.

Incidentally, it is known to the art that the heat

20   conductivity of a material under a thin film state
differs from that under a bulk state. However, if the
two different types of materials are compared in
respect of the heat conductivity under the thin film
state or under the bulk state, the relationship between

25   these two materials in respect of the magnitude of
the heat conductivity is substantially independent of
the state of the material. Such being the situation,

the heat conductivities referred herein represent those
under the bulk state.

Then, optical characteristics of the optical
recording medium were calculated in order to obtain
appropriate design conditions for each of the films
included in the phase-change optical recording medium
according to the embodiments of the present invention.
To be more specific, the optical characteristics
(a refractive index and an attenuation coefficient) as
well as the thickness for the material of each film
were set at prescribed values, and simultaneous
equations were formed in respect of the optical energy
balance for every interface based on the energy
conservation law, followed by solving the simultaneous
equations. By these calculations, it is possible to
obtain reflectance and transmittance of the entire
multi-layered film as well as absorbance of each film.
This method is known as the matrix method, as described
in, for example, Hiroshi Kubota et al., "Wave Optics",
Iwanami Shoten Publishers, 1971. Here, the reflectance
and the transmittance of the first information layer
(semi-transparent information layer) were calculated on
an assumption that a light beam having a wavelength of
405 nm is incident on the phase-change optical
recording medium shown in FIG. 8.

In the followings, suitable ranges of the
refractive index and the thickness of each film were

examined based on the reflectance Rc when the recording

film is in a crystalline phase, the reflectance Ra when

the recording film is in an amorphous phase, the

contrast (Rc - Ra)/(Rc + Ra), and the average

5   transmittance of the recording film under the

crystalline phase or the amorphous phase. It is

desirable that the change in each of Rc, Ra and the

average transmittance be small even if the refractive

index and the thickness of each film are changed.

10   Also, it is desirable that the contrast exhibits a high

value when the refractive index and the thickness of

each film fall within suitable ranges.

The present inventors have found first that it is

desirable that the refractive index of the heat sink

15   film be close to the refractive index of a UV curable

resin in contact with the heat sink film. To be more

specific, it is desirable that the difference between

the refractive index of the heat sink film and that of

the UV curable resin be 0.5 or less and, more

20   preferably, be 0.3 or less. This will now be described

in detail.

The optical constants were calculated in respect

of the optical recording medium having a stacked

structure in which a first interference film $ZnS:SiO_2$,

25   a lower interface film HfO_2, a phase-change optical

recording film GeSbTeBi, an upper interface film HfO_2,

a second interference film $ZnS:SiO_2$, a reflection film

AgPdCu, a heat sink film and a UV curable resin are formed on a first substrate. The refractive index n_r of the UV curable resin was set to 1.52. The refractive index n_{hs} of the heat sink film was set to 1.8 or 2.7.

Graphs relating to the combinations of a thickness of the second interference film ($ZnS:SiO_2$) as an x-coordinate and a thickness of the heat sink film as a y-coordinate were prepared in respect of the first information layer (semi-transparent information layer) included in the optical recording medium using heat sink films differing from each other in the refractive index. In a case where satisfactory optical characteristics can be obtained if the thickness of the first interference film ($ZnS:SiO_2$) is set appropriately, the point corresponding to the particular combination is plotted in the graph. Incidentally, the satisfactory optical characteristics referred to above denote that the contrast of at least 0.8 and the average transmittance of at least 50% are satisfied.

The experimental data are given in FIG. 10A [n_{hs} = 1.8] and FIG. 10B [n_{hs} = 2.7]. FIG. 10A supports that, where n_{hs} is close to n_r, it is possible to obtain satisfactory optical characteristics even if the thickness of each of the second interference film and the heat sink film are changed over a considerably

wide range. In particular, satisfactory optical characteristics can be obtained where the thickness of the second interference film falls within a desirable range of between 5 nm and 30 nm. On the other hand, FIG. 10B supports that, where n_{hs} widely differs from n_r, the range of the film thickness within which satisfactory optical characteristics can be obtained is considerably limited.

The thermal characteristics of the phase-change optical recording medium are greatly dependent on not only the heat conductivity of each of the interface film and the heat sink film but also on the thickness of each of the films, in particular, the thickness of the interference film on the side of the reflection film. Therefore, the fact that satisfactory optical characteristics can be obtained over a wide range of the film thickness indicates that it is possible to obtain easily both the satisfactory optical characteristics and the thermal characteristics.

Then, changes in the optical constants of the optical recording medium caused by changes in the refractive index n_{hs} and the thickness t_{hs} of the heat sink film were examined. In this case, the optical constants were calculated in respect of the optical recording medium of a structure: $ZnS:SiO_2$ (50 nm)/HfO_2 (3 nm)/GeSbTeBi (6 nm)/HfO_2 (3 nm)/$ZnS:SiO_2$ (20 nm)/AgPdCu (6 nm)/heat sink film/UV curable resin.

The refractive index n_r of the UV curable resin was set at 1.52 or 1.8.

The changes in the optical characteristics (Rc, Ra, contrast, average transmittance) of the first information layer (semi-transparent information layer) were calculated in accordance with the refractive index n_{hs} and the thickness t_{hs} of the heat sink film where the absorption of the heat sink film was set at 0. FIGS. 11A and 11B show the results. FIG. 11A shows the results of the calculations, covering the case where the refractive index n_r of the UV curable resin was set at 1.52, and FIG. 11B shows the results of the calculations, covering the case where the refractive index n_r of the UV curable resin was set at 1.80.

Each of FIGS. 11A and 11B supports that, if the refractive index n_{hs} of the heat sink film is close to the refractive index n_r of the UV curable resin, the changes in the optical characteristics of the semi-transparent information layer caused by the changes in the thickness t_{hs} of the heat sink film is small, i.e, the distribution of the contour lines is made sparse. In the semi-transparent information layer included in the phase-change optical recording medium according to the embodiments of the present invention, the cooling effect produced by the heat sink film is much higher than that produced by the reflection film or the interference film. As a result, the cooling

effect of the entire semi-transparent information layer

is greatly changed by the thickness t_{hs} of the heat

sink film. FIGS. 11A and 11B imply that, if n_{hs} is

close to n_r, the optical characteristics of the

semi-transparent information layer are scarcely changed

even if the thickness t_{hs} of the heat sink film is

changed in an attempt to optimize the cooling effect of

the entire semi-transparent information layer. This is

a very great advantage in terms of the thermal design.

The results given in FIGS. 10A, 10B, 11A and 11B

support that it is desirable the value of $|n_{hs} - n_r|$ be

smaller than 0.5, in particular, it is more desirable

for that a relationship $n_r < n_{hs} < n_r + 0.3$ be

satisfied.

Then, changes in the optical constants of the

optical recording medium caused by changes in the

thicknesses t_{d1} and t_{d2} of the first and second

interference films were examined. In this case, the

optical constants were calculated in respect of the

optical recording medium of the structure: $ZnS:SiO_2$

(x nm)/HfO_2 (3 nm)/GeSbTeBi (6 nm)/HfO_2 (3 nm)/$ZnS:SiO_2$

(y nm)/AgPdCu (6 nm)/SiO_2 or TiO_2 (30 nm)/UV curable

resin. The refractive index n_r of the UV curable resin

was set at 1.52. The refractive index n_{hs} of the heat

sink film was about 1.5 for SiO_2 and about 2.9 for

TiO_2. FIGS. 12A and 12B show the results. FIG. 12A

shows the results of the calculations in the case where

SiO_2 was used for the heat sink film, and FIG. 12B shows the results of the calculations in the case where TiO_2 was used for the heat sink film.

As shown in FIG. 12A, where the refractive index n_{hs} of the heat sink film is close to the refractive index n_r of the UV curable resin, the changes in the optical characteristics of the first information layer (semi-transparent information layer) is relative small, i.e., the distribution of the contour lines is made sparse, even if the thicknesses t_{d1}, t_{d2} of the first and second interference films on the upper and lower sides of the recording film are much changed. On the other hand, FIG. 12B shows that, in the case where the refractive index n_{hs} of the heat sink film is much different from the refractive index n_r of the UV curable resin, the optical characteristics of the first information layer (semi-transparent information layer) is greatly changed, i.e., the distribution of the contour lines is made dense, even if the thicknesses t_{d1}, t_{d2} of the first and second interference films on the upper and lower sides of the recording film are slightly changed.

Like the thickness of the heat sink film, the thickness of each of the first and second interference films on the upper and lower sides of the recording film greatly affects the cooling effect of the first information layer (semi-transparent information layer).

Therefore, the fact that the optical characteristics of the first information layer (semi-transparent information layer) are not greatly dependent on the thickness of the interference films as shown in FIG. 12A provides a significant advantage in optimizing the cooling effect and in avoiding the changes in the characteristics caused by the unevenness of film thickness induced in the deposition process.

Then, changes in the optical characteristics of the optical recording medium caused by changes in the thicknesses t_{d1} and t_{d2} of the first and second interference films were examined as described above, using cerium oxide in place of hafnium oxide for the interface film. The optical constants were calculated in respect of the optical recording medium of the structure: ZnS:SiO$_2$ (x nm)/CeO$_2$ (3 nm)/GeSbTeBi (6 nm)/CeO$_2$ (3 nm)/ZnS:SiO$_2$ (y nm)/AgPdCu (6 nm)/SiO$_2$ or TiO$_2$ (30 nm)/UV curable resin. FIGS. 13A and 13B show the results. FIG. 13A shows the results of the calculations in the case where SiO$_2$ (refractive index: about 1.5) was used for the heat sink film, and FIG. 13B shows the results of the calculations in the case where TiO$_2$ (refractive index: about 2.9) was used for the heat sink film.

Like FIGS. 12A and 12B, FIGS. 13A and 13B also support that optical characteristics can be obtained over a wide range of the film thicknesses t_{d1} and t_{d2}

if the refractive index n_{hs} of the heat sink film is close to the refractive index n_r of the UV curable resin.

In the phase-change optical recording medium according to still another embodiment of the present invention, it is possible to use an objective lens having a high NA of about 0.85 and to irradiate the phase-change optical recording film with a light beam transmitted through the transparent sheet having a thickness of about 0.1 mm. In this case, the reflection film 16, the second interference film 15, the upper interface film 14, the recording film 13, the lower interface film 12, and the first interference film 11 are deposited in the order mentioned on the substrate having a thickness of about 1.1 mm, followed by finally bonding a thin transparent sheet having a thickness of about 0.1 nm to the film stack so as to manufacture the desired phase-change optical recording medium.

It is also possible to irradiate the recording films of a dual-layer single-sided optical recording medium with a light beam transmitted through a thin transparent sheet having a thickness of about 0.1 mm. In this case, a reflection film, a second interference film, an upper interface film, a recording film, a lower interface film and a first interference film are deposited successively in the order mentioned on

a substrate. Then, a thin layer of ultraviolet curable resin having a suitable thickness of 10 nm to 50 nm is formed by spin-coating. Further, the resin is cured under the state that a stamper for forming a groove is

5   pressed against the resin, followed by peeling off the stamper. Subsequently, a reflection film, a second interference film, an upper interface film, a recording film, a lower interface film and a first interference film are deposited in the order mentioned on the cured

10   resin. Still further, a thin transparent film having a thickness of about 0.1 mm is bonded or a resin film having a thickness of about 0.1 mm is formed. In this fashion, it is possible to form a dual-layer recording medium conforming to a high NA of about 0.85.

15   In the above particular structure, the interface films are formed on both sides of the recording film. However, it is possible to omit either one of the interface films without deviating from the subject matter of the present invention. Also, it is possible

20   to omit the interference film, as required, so as to form the interface film alone.

<div align="center">EXAMPLES</div>

Examples of the present invention will now be described.

25   Examples A to H and Comparative Examples:

In each of the Examples, the phase-change optical disc was fabricated as follows. Specifically,

a polycarbonate substrate having a thickness of 0.6 mm,
formed by injection molding, was used as the substrate.
Grooves were formed on the polycarbonate substrate at a
pitch of 0.74 μm. Therefore, in the case of land and
5   groove recording, the track pitch comes to 0.37 μm.
Various films were successively deposited by sputtering
on that surface of the polycarbonate substrate on which
the grooves were formed. A so-called cluster type
sputtering apparatus, in which each film is deposited
10   in a different chamber, was used. A target having
a composition corresponding to that of the film to be
deposited was mounted in each of the chambers. Since
the sputtering apparatus was provided with a vacuum
transfer chamber, the substrate was transferred under
15   vacuum until deposition processes of all the films were
completed.

The phase-change optical recording medium thus
obtained was mounted to an initializing apparatus so as
to crystallize the recording film on the entire surface
20   thereof. Then, the phase-change optical recording
medium was evaluated by using a disc evaluating
apparatus DDU-1000 manufactured by Pulstec Industrial
Co., Ltd. The apparatus was equipped with a blue-
violet semiconductor laser having a wavelength of 405
25   nm and an objective lens of NA 0.65. Experiments by
the land and groove recording were carried out for the
phase-change optical disc. Reflectance Rc of

a crystalline portion and reflectance Ra of

an amorphous portion were measured. Also, as described

in the followings, an error rate of the data was

evaluated by the bit error rate (bER) measurement, and

5 read signal qualities were evaluated by analog

measurements. A carrier-to-noise ratio (CNR), a DC

erasure rate, and cross-erase (X-E) were determined by

the analog measurements. Each of the measurements was

performed in respect of the tracks on the groove (G)

10 and the land (L).

In the land and groove recording, the track pitch

becomes 0.37 μm as described above. The linear

velocity of the disc was set at 6.7 m/s. In the

following description, the 2T mark has a mark length of

15 0.21 μm, and the 9T mark has a mark length of 0.95 μm.

The bER measurement was carried out as follows.

First, a mark train containing marks of 2T to 9T at

random was overwritten 10 times in a target track.

Then, the same random pattern was overwritten 10 times

20 in each of the adjacent tracks on both sides of the

target track, followed by measuring the bER on the

target track.

The analog measurements were carried out as

follows. First, a mark train containing marks of 2T to

25 9T at random was overwritten 10 times in a target

track. Then, a 9T mark train (single pattern)

was overwritten once in the target track.

The carrier-to-noise ratio (CNR) of the signal frequency of the 9T marks was measured with a spectrum analyzer. Then, the target track was irradiated with a laser beam at an erasing power level during one

5   rotation of the disc so as to erase the recording marks, followed by determining decrease in the signal level of the 9T marks. This is defined as a DC erasure rate. Also, the head was moved to a sufficiently remote track, and cross-erase (X-E) measurement was

10   carried out as follows. First, a 2T mark train was overwritten 10 times in a target track, followed by measuring the signal level of the 2T marks with a spectrum analyzer. Then, a 9T mark train was overwritten 10 times in each of the adjacent tracks on

15   both sides of the target track. Thereafter, the head was brought back to the target track where the 2T mark train was written so as to measure again the signal level of the 2T marks. The decrease in the signal level of the 2T marks relative to the level measured

20   first was defined as the cross-erase value.

Examples A to F and Comparative Examples:

Phase-change optical discs having various stacked structures were fabricated. Tables 1 to 3 show the structure of each of the phase-change optical disc and

25   the evaluation results.

Table 1

	Example A	Comparative Example A1	Comparative Example A2	Comparative Example A3
1st interference film	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 53nm
Lower interface film	HfO$_2$ 3nm	GeN 3nm	SiN 3nm	None
Recording film	Ge$_{40}$Sb$_8$Te$_{52}$ 13nm	Ge$_{40}$Sb$_8$Te$_{52}$ 13nm	Ge$_{40}$Sb$_8$Te$_{52}$ 13nm	Ge$_{40}$Sb$_8$Te$_{52}$ 13nm
Upper interface film	HfO$_2$ 3nm	GeN 3nm	SiN 3nm	None
2nd interference film	ZnS:SiO$_2$ 15nm	ZnS:SiO$_2$ 15nm	ZnS:SiO$_2$ 15nm	ZnS:SiO$_2$ 18nm
Reflective film	Ag alloy 150nm	Ag alloy 150nm	Ag alloy 150nm	Ag alloy 150nm
Rc	19.2	18.6	18.4	19.3
Ra	2.4	2.2	2.1	2.3
bER (G)	$1.40*10^{-5}$	$4.80*10^{-4}$	$9.20*10^{-3}$	$>1*10^{-2}$
bER (L)	$1.25*10^{-5}$	$4.70*10^{-4}$	$7.60*10^{-3}$	$>1*10^{-2}$
CNR (G) [dB]	56.4	56.2	54.6	46.4
CNR (L) [dB]	56.2	55.8	53.8	45.8
Erasure rate (G) [dB]	-33.2	-30.2	-21.4	-2.4
Erasure rate (L) [dB]	-34.2	-31.2	-18.5	-1.5
X-E (G) [dB]	-0.2	-3.5	-1.2	0
X-E (L) [dB]	0	-0.7	-0.3	0

Table 2

	Example B	Example C	Example D1	Example D2	Comparative Example D
1st interference film	ZnS:SiO$_2$ 50nm	None	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm
Lower interface film	HfO$_2$-CeO$_2$ 3nm	HfO$_2$-ZrO$_2$ 55nm	HfO$_2$ 3nm	HfO$_2$ 3nm	GeN 3nm
Recording film	Ge$_{40}$Sb$_8$Te$_{52}$ 13nm	Ge$_{40}$Sb$_8$Te$_{52}$ 13nm	Ge$_{31}$Sb$_{15}$Te$_{54}$ 13nm	Ge$_{22}$Sb$_{22}$Te$_{56}$ 13nm	Ge$_{22}$Sb$_{22}$Te$_{56}$ 20nm
Upper interface film	HfO$_2$-CeO$_2$ 3nm	HfO$_2$-ZrO$_2$ 20nm	HfO$_2$ 3nm	HfO$_2$ 3nm	GeN 3nm
2nd interference film	ZnS:SiO$_2$ 15nm	None	ZnS:SiO$_2$ 15nm	ZnS:SiO$_2$ 15nm	ZnS:SiO$_2$ 15nm
Reflective film	Ag alloy 150nm	Ag alloy 150nm	Ag alloy 150nm	Ag alloy 150nm	Ag alloy 150nm
Rc	20.4	19.4	17.5	15.4	18.4
Ra	1.9	1.6	1.9	2	3.5
bER (G)	2.20*10^{-5}	6.20*10^{-6}	2.00*10^{-5}	1.80*10^{-5}	> 1*10^{-2}
bER (L)	1.80*10^{-5}	4.20*10^{-6}	2.20*10^{-5}	2.10*10^{-5}	> 1*10^{-2}
CNR (G) [dB]	55.5	56.8	54.2	53.4	51.6
CNR (L) [dB]	56.2	55.2	53.6	52.8	50.5
Erasure rate (G) [dB]	-29.4	-28.5	-34.2	-37.2	-29.6
Erasure rate (L) [dB]	-30.1	-27.4	-35.3	-39.2	-30.4
X-E (G) [dB]	-0.3	-0.4	-0.5	-0.8	-6.8
X-E (L) [dB]	0	0	0	-0.3	-4.5

– 50 –

Table 3

	Example E1	Example E2	Example F
1st interference film	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm
Lower interface film	HfO$_2$ 3nm	HfO$_2$ 3nm	HfO$_2$ 3nm
Recording film	Ge$_{40}$Sb$_4$Bi$_4$Te$_{52}$ 10nm	Ge$_{23}$Sn$_8$Sb$_{15}$Te$_{54}$ 10nm	Ge$_{40}$Sb$_8$Te$_{52}$ 20nm
Upper interface film	HfO$_2$ 3nm	HfO$_2$ 3nm	HfO$_2$ 3nm
2nd interference film	ZnS:SiO$_2$ 15nm	ZnS:SiO$_2$ 15nm	ZnS:SiO$_2$ 15nm
Reflective film	Ag alloy 150nm	Ag alloy 150nm	Ag alloy 150nm
Rc	19.1	18.2	21.5
Ra	2.2	2.1	2.2
bER (G)	$2.40*10^{-5}$	$1.70*10^{-5}$	$3.20*10^{-5}$
bER (L)	$1.20*10^{-5}$	$9.00*10^{-6}$	$2.50*10^{-5}$
CNR (G) [dB]	54.2	54.6	56.2
CNR (L) [dB]	53.8	53.2	56.3
Erasure rate (G) [dB]	-31	-32.2	-31.6
Erasure rate (L) [dB]	-30.5	-31.2	-30.2
X-E (G) [dB]	0	-0.2	-0.9
X-E (L) [dB]	0	0	-0.3

Example A (HfO$_2$ Interface Film):

A phase-change optical disc (Example A) as shown in FIG. 3 was fabricated. The material used for each film and the thickness thereof were as follows:

5

First interference film 11   ZnS:SiO$_2$ (50 nm);

Lower interface film 12   HfO$_2$ (3 nm);

Recording film 13   Ge$_{40}$Sb$_8$Te$_{52}$ (13 nm);

Upper interface film 14   HfO$_2$ (3 nm)

Second interference film 15   ZnS:SiO$_2$ (15 nm);

10

Reflection film 16   Ag alloy (150 nm).

The disc of Example A exhibited a bit error rate (bER) lower than 2×10^{-5} for each of the land and the groove, which was permissible level for a practical use. The excellent bER is also supported by the excellent analog characteristics including CNR higher

15

than 56 dB, the erasure rate lower than -29 dB and the cross-erase of -0.2 dB or less. In other words, a satisfactory bER can be obtained because the CNR is excellent and the cross-erase is low in the case of

20

using HfO$_2$ for the interface film.

Comparative Example A1 (GeN Interface Film) and Comparative Example A2 (Si-N Interface Film):

For comparison, phase-change optical discs having the stacked structure equal to that of Example A were

25

fabricated, except that GeN and Si-N were used for the interface films in Comparative Examples A1 and A2, respectively.

The disc of each of Comparative Examples A1 and A2 was found to be inferior in the bER compared to Example A by 1 to 2 digits. To be more specific, the disc of Comparative Example A1, in which the interface film was formed of GeN, was found to be poor in the bER because the cross-erase was likely to be generated easily. The disc of Comparative Example A2, in which the interface film was formed of Si-N, was found to be poor in the bER because the CNR was low.

Incidentally, it is possible to improve either the CNR or the cross-erase to some extent by controlling the thickness of the interface film even in the case of using GeN or Si-N. However, it is impossible to improve simultaneously both the CNR and the cross-erase.

Comparative Example A3 (No Interface Film):

For comparison, a phase-change optical disc (Comparative Example A3) having a stacked structure in which the interface films are omitted from the disc of Example A was fabricated.

In the disc of Comparative A3, it was impossible to measure the bER. Also, in the disc of Comparative Example A3, the CNR value was also very small, which reflects the poor erasure rate in overwriting. It follows that, in the disc of Comparative Example A3, it was substantially impossible to achieve rewriting under the evaluating conditions employed.

Example B (Change in Composition of Interface Film):

A phase-change optical disc (Example B) having the stacked structure equal to that of Example A was fabricated, except that HfO_2-CeO_2 (the molar ratio of 60:40) was used for the interface films in place of HfO_2.

The disc of Example B was somewhat inferior to the disc of Example A in respect of the cross-erase X-E, but was superior to the disc of Example A in each of the CNR and the erasure rate.

Example C (Omission of Interference Film):

A phase-change optical disc (Example C) in which the interference films were omitted as shown in FIG. 5 and HfO_2-ZrO_2 (the molar ratio of 40:60) is used for the interface films was fabricated. Incidentally, in accordance with omission of the interference films, the thickness of the lower interface film 12 on the light incident side was set at 55 nm, and the thickness of the upper interface film 14 on the side of the reflection film was set at 20 nm.

The disc of Example C was found to be excellent in each of the cross-erase X-E, the CNR, and the erasure rate. Also, since the total number of the films in the disc of Example C was smaller by two than that for Example A, it was possible to decrease the deposition processes, which brings about superior productivity.

Where the interference films, which were widely
used in the prior art, are omitted and the interface
films alone specified in the present invention are
formed in place of the interference films, it is

5 desirable to pay sufficient attentions to the
combination of the thickness and the heat conductivity
of the interface film. To be more specific, if the
interface film has excessively high heat conductivity,
it is difficult to heat the recording film to reach the

10 melting point thereof. On the other hand, if the heat
conductivity of the interface film is excessively low,
recrystallization in the melted region of the recording
film is rendered prominent, with the result that
decrease in CNR and generation of cross-erase are

15 promoted.

In the disc of Example C, HfO_2-ZrO_2 was used for
the interface films, and the interface films formed on
the light incident side and on the side of the
reflection film relative to the recording film were

20 made somewhat thicker so as to lead to the satisfactory
results.

Also, it is desirable to mix other elements and
compounds containing other elements for controlling the
heat conductivity. For example, it is possible to use

25 a mixture of HfO_2 and $ZnS:SiO_2$ for the interface film.

Incidentally, in Example C, the interference films
on the light incident side and on the side of

the reflection film relative to the recording film are omitted. However, it is also possible to omit the interference film on the light incident side alone relative to the recording film as shown in FIG. 4.

5 Also, it is possible to omit only the interference film on the side of the reflection film relative to the recording film.

Examples D1, D2 and Comparative Example D (Influences Given by Composition of Recording Film):

10 A phase-change optical disc (Example D1) having the stacked structure equal to that of Example A was fabricated, except that the composition of the recording film was changed to $Ge_{31}Sb_{15}Te_{54}$ (Ge : Sb : Te = 4 : 2 : 7), lower in the Ge content than that for

15 Example A.

The disc of Example D1 was somewhat superior to the disc of Example A in the erasure rate, but was inferior in the CNR and the cross-erase X-E. However, a high cross-erase X-E as in Comparative Example A1 and

20 a low erasure rate as in Comparative Example A2 were not observed in the disc of Example D1, supporting that the evaluation results for Example D1 were free from a practical problem. Therefore, it is believed that the effects due to the use of the HfO_2 interface film can

25 be produced even in the case of changing the composition of the recording film.

Also, a phase-change optical disc (Example D2)

having the stacked structure equal to that of Example A was fabricated, except that the composition of the recording film was changed to $Ge_{22}Sb_{22}Te_{56}$. It should be noted that the Ge content in the recording film for

5 Example D2 is much lower than that in the recording film for Example D1.

The disc of Example D2 exhibited a particularly excellent value in respect of the erasure rate, but was interior to the disc of Example D1 in each of the CNR

10 and the cross-erase X-E. However, a high cross-erase X-E as in Comparative Example A1 and a low erasure rate as in Comparative Example A2 were not observed in the disc of Example D2, supporting that the evaluation results for Example D2 were free from a practical

15 problem.

The reason why the disc of Example D2 is inferior to Example D1 in the CNR is that change in the optical characteristics (complex refractive indices n and k), between a crystalline phase and an amorphous phase is

20 decreased with decrease in the Ge content of the recording film.

In order to confirm the particular situation, a phase-change optical disc (Comparative Example D) having the stacked structure equal to that of

25 Example D2 was fabricated, except that the interface film was changed to the conventional interface film made of GeN.

In the disc of Comparative Example D, the CNR was further degraded to about 51 dB, compared with the disc of Example D2. Also, in the disc of Comparative Example D, the cross-erase X-E to the groove was high, i.e., -6.8 dB, and the cross-erase X-E to the land was much higher, i.e., -4.5 dB.

Such being the situation, it has been confirmed that, in the case of using HfO_2 for the interface films, the CNR can be increased and the cross-erase X-E can be lowered, compared with the case of using the conventional interface film, even if the recording film is formed of GeSbTe having a low Ge content.

As described above, the interface film specified in the present invention permits prominent effects when used in combination with a GeSbTe recording film having a low Ge content, compared with the conventional interface film, and also permits a further prominent effects when used in combination with a GeSbTe recording film having a higher Ge content.

Examples E1 and E2 (Influences Produced by Composition of Recording Film, Substitution of Bi and Sn):

A phase-change optical disc (Example E1) having the stacked structure equal to that of Example A was fabricated, except that Bi was substituted partly for Sb contained in the material of the recording film such that the composition of the recording film was

changed to $Ge_{40}Sb_4Bi_4Te_{52}$ (Ge : Sb : Bi : Te = 10 : 1 : 1 : 13).

The disc of Example E1 was somewhat inferior in the CNR to the disc of Comparative Example A1, but it was substantially free from the practical problem in the CNR value. The disc of Example E1 was superior in the erasure rate to the disc of Comparative Example A1, and thus it was free from the practical problem in the erasure rate. Also, the decrease in the signal level was not recognized at all in the disc of Example E1 even if the overwriting was performed 10 times on the adjacent tracks, with the result that the cross-erase X-E was particularly low. Such being the situation, the CNR after recording of signals on the adjacent tracks was found to be larger than the CNR after recording similarly performed on the adjacent tracks in Example A1. Therefore, it is found that prominent effects can also be produced in the case where the HfO_2 interface film is used in combination with the GeSbBiTe recording film.

A phase-change optical disc (Example E2) having the stacked structure equal to that of Example D2 was fabricated, except that Sn was substituted partly for Ge contained in the material of the recording film such that the composition of the recording film was changed to $Ge_{23}Sn_8Sb_{15}Te_{54}$ (Ge : Sn : Sb : Te = 3 : 1 : 2 : 7).

The disc of Example E2 was somewhat inferior in

the CNR to the disc of Comparative Example A1 but

substantially equal to the disc of Comparative

Example A2, which was substantially free from the

practical problem in the CNR. The disc of Example E2

was superior in the erasure rate to the disc of

Comparative Example A1, and thus it was free from the

practical problem in the erasure rate. Also, the disc

of Example E2 was particularly low in the cross-erase

X-E. Such being the situation, the CNR after recording

of signals on the adjacent tracks was found to be

larger than that in Example A1. Therefore, it is found

that prominent effects can also be produced in the case

where the HfO_2 interface film is used in combination

with the GeSnSbTe recording film.

Example F (Influence Given by Thickness of

Recording Film):

A phase-change optical disc (Example F) having the

stacked structure equal to that of Example A was

fabricated, except that the thickness of the recording

film was set at 20 nm.

The disc of Example F was superior in the overall

characteristics to disc of each of Comparative

Examples A1 and A2. On the other hand, the disc of

Example F was substantially compared with the disc of

Example A in the CNR and the erasure rate, but it was

inferior to the disc of Example A in the cross-erase

X-E. Therefore, it is desirable that the thickness of

the recording film be smaller than 20 nm.

Examples G, H and Comparative Example:

Phase-change optical discs each having Low-to-High polarity, in which the reflectance Ra of the amorphous portion is higher than the reflectance Rc of the crystalline portion, were fabricated. Table 4 shows the structure of each of the phase-change optical discs and the evaluation results.

Table 4

	Example G	Comparative Example G	Example H
1st interference film	ZnS:SiO$_2$ 30nm	ZnS:SiO$_2$ 30nm	ZnS:SiO$_2$ 30nm
	SiO$_2$ 90nm	SiO$_2$ 90nm	SiO$_2$ 90nm
	ZnS:SiO$_2$ 20nm	ZnS:SiO$_2$ 20nm	—
Lower interface film	HfO$_2$-ZrO$_2$ 3nm	GeN 3nm	HfO$_2$-ZrO$_2$ 25nm
Recording film	Ge$_{40}$Sb$_8$Te$_{52}$ 13nm	Ge$_{40}$Sb$_8$Te$_{52}$ 13nm	Ge$_{40}$Sb$_8$Te$_{52}$ 13nm
Upper interface film	HfO$_2$-ZrO$_2$ 3nm	GeN 3nm	HfO$_2$-ZrO$_2$ 23nm
2nd interference film	ZnS:SiO$_2$ 20nm	ZnS:SiO$_2$ 20nm	None
Reflective film	Ag alloy 150nm	Ag alloy 150nm	Ag alloy 150nm
Rc	5.5	5.2	5.8
Ra	27.3	27.5	28.5
bER (G)	$7.2*10^{-6}$	$4.5*10^{-5}$	$5.8*10^{-6}$
bER (L)	$5.6*10^{-6}$	$8.2*10^{-5}$	$6.2*10^{-6}$
CNR (G) [dB]	58.9	54.3	58.2
CNR (L) [dB]	58.2	55.2	58.4
Erasure rate (G) [dB]	-33.3	-32.1	-33.8
Erasure rate (L) [dB]	-32.7	-31.8	-33.1
X-E (G) [dB]	-0.4	-4.2	-0.3
X-E (L) [dB]	-0.1	-1.5	0

Example G (Low-to-High Disc using Interference Film of Three-Layer Structure):

A phase-change optical disc (Example G) having Low-to-High polarity was fabricated. The material used for each of the films and the thickness of each film were as follows:

First interference film 11

$ZnS:SiO_2$ (30 nm)/SiO_2 (90 nm)/$ZnS:SiO_2$ (20 nm);

Lower interface film 12 HfO_2-ZrO_2 (3 nm);

Recording film 13 $Ge_{40}Sb_8Te_{52}$ (13 m);

Upper interface film 14 HfO_2 (3 nm);

Second interference film 15 $ZnS:SiO_2$ (20 nm);

Reflection film 16   Ag alloy (150 nm).

In this disc, it was possible to achieve a large modulation degree such that the reflectance Ra of the amorphous portion was 27.3% and the reflectance Rc of the crystalline portion was 5.5%. Also, the disc was particularly excellent in the CNR and exhibited a very low in the bER because it was excellent in the erasure rate and the cross-erase X-E.

Comparative Example G (GeN Interface Film):

For comparison, a phase-change optical disc (Comparative Example G) having the stacked structure equal to that of Example G was fabricated, except that GeN was used for the interface films.

The disc of Comparative Example G was excellent in the reflectance difference like the disc of Example G,

but it was inferior in the CNR. This is because the
region that was once melted in the write stage was not
entirely rendered amorphous and was partly
recrystallized so that the poor CNR was brought about.
In this connection, the disc of Comparative Example G
was also inferior in the bER compared to the disc of
Example G.

Example H (Omission of Interference Films):

A phase-change optical disc (Example H) having the
stacked structure equal to the disc of Example G was
fabricated, except that $ZnS:SiO_2$ positioned close to
the recording film 13 of the first interference film 11
and the second interference film 15 were omitted.
Incidentally, in accordance with omission of the
interference films, the thickness of the lower
interface film 12 on the light incident side was set at
25 nm, and the thickness of the upper interface film 14
on the side of the reflection film was set at 23 nm.

The disc of Example H was found to be high in each
of the CNR value and the erasure rate. In addition,
the disc was excellent in productivity.

Examples L to U and Comparative Examples:

Dual-layer single-sided phase-change optical discs
as shown in FIG. 8 were prepared. A 0.6 mm-thick
polycarbonate substrate, formed by injection molding,
was used as the substrate. Grooves were formed on
the polycarbonate substrate with a groove pitch of

0.74 μm. Therefore, in the case of land and groove
recording, the track pitch comes to 0.37 μm. Various
films were successively deposited using a sputtering
apparatus on that surface of the polycarbonate
substrate on which the grooves were formed so as to
form a first information layer (semi-transparent
information layer). On the other hand, a stacked
structure of Ag alloy/ZnS:SiO$_2$/GeSbTe recording
film/ZnS:SiO$_2$ was formed by sputtering on the surface
of another 0.6 mm-thick polycarbonate substrate so as
to prepare a second information layer. The recording
film of the second information layer was entirely
subjected to initial crystallization using an
initializing apparatus. The substrates were arranged
in a manner that the first and second information
layers face each other and were bonded with a UV
curable resin layer. The dual-layer single-sided
phase-change optical disc thus prepared was set in an
initializing apparatus, and the recording film of the
first information layer was entirely subjected to
initial crystallization. Then, recording experiments
were carried out using the same evaluating apparatus as
described above, in which the pick-up head of the
evaluation apparatus was focused on the first
information layer to carry out land and groove
recording. The bit error rate bER, the carrier-to-
noise ratio CNR, the DC erasure rate, and the

cross-erase (X-E) were evaluated in the same manner as described above. Any of these measurements was applied to the tracks on the groove (G) and the land (L).

Example L:

On the first substrate, $ZnS:SiO_2$ (the first interference film)/HfO_2 (the lower interface film)/GeSbTe (the recording film)/HfO_2(the upper interface film)/SiO_2 (the second interference film)/Ag alloy (the semi-transparent reflection film)/SiO_2 (the heat sink film) were successively deposited in the order mentioned so as to form a first information layer (semi-transparent information layer). The thickness of each of the films is shown in Table 5.

The recording film was formed using a target having a composition of $Ge_{40}Sb_8Te_{52}$ (Ge : Sb : Te = 10 : 2 : 13). The first interference film of $ZnS:SiO_2$ was formed using a target containing 80 at.% of ZnS and 20 at.% of SiO_2.

The refractive index of the UV curable resin was about 1.5 and the refractive index of SiO_2 heat sink film was about 1.5 for recording light having a wavelength of 405 nm. Also, the heat conductivity of the HfO_2 interface film was 1.8 W/mK and the heat conductivity of the SiO_2 heat sink film was 1.3 W/mK.

Table 5 shows the measurement results in respect of the disc thus fabricated. The bit error rate (bER) was not higher than 6×10^{-5} for each of the land and

the groove, and thus there was no practical problem.
It is considered that the excellent bER can be obtained
because the disc exhibited excellent characteristics in
the analog measurements such that the CNR was not lower
than 52 dB for each of the land and the groove, the
erasure rate was not higher than -25 dB, and the cross-
erase was not higher than -0.2 dB. This clearly
exhibits the feature that there is no trade-off between
CNR and cross-erase (X-E) when HfO_2 is used for the
interface film.

Incidentally, it is desirable for each film to
have a thickness falling within the range described
below. The first interference film such as $ZnS:SiO_2$ on
the light incident side should preferably have a
thickness from 30 nm to 160 nm and a range within which
desired reflectance is satisfied. The interface films
should preferably have a thickness of 5 nm or less.
The recording film should preferably have a thickness
falling within a range of between 5 nm and 8 nm.
The second interference film positioned close to the
reflection film should preferably have a thickness
falling within a range of between 5 nm and 30 nm.
The reflection film should preferably have a thickness
falling with a range of between 5 nm and 10 nm.
The heat sink film should preferably have a thickness
falling within a range of between 10 nm and 100 nm.

Examples M1 and M2 (Change in Composition of

Recording Film):

A phase-change optical disc (Example M1) having the stacked structure equal to that of Example L was fabricated, except that the composition of the recording film was changed to $Ge_{40}Sb_4Te_{52}Bi_4$ (Ge : Sb : Te : Bi = 10 : 1 : 13 : 1). Table 5 shows the evaluation results. The disc of Example M1 was superior in each of CNR, erasure rate and X-E compared to those of Example L.

Similarly, a phase-change optical disc (Example M2) having the stacked structure equal to that of Example L was fabricated, except that the composition of the recording film was changed to $Ge_{23}Sb_{15}Te_{54}Sn_8$ (Ge : Sb : Te : Sn = 3 : 2 : 7 : 1, the sum of Ge and Sn being 31 at.%). Table 5 shows the evaluation results. The disc of Example M2 was somewhat inferior in CNR compared to the disc of Example L, though the CNR value did not bring about a practical problem. Also, the disc of Example M2 was superior in each of the erasure rate and X-E compared to the disc of Example L.

Example N (Change in Materials of Second Interference Film and Heat Sink Film):

The material of the second interference film was changed to $ZnS:SiO_2$ and the material of the heat sink film was changed to Al_2O_3 with respect to the disc of Example M1. Thus, a phase-change optical disc

(Example N) of the following structure was fabricated:
$ZnS:SiO_2/HfO_2/GeSbTeBi/HfO_2/ZnS:SiO_2/Ag$ alloy/Al_2O_3.
The refractive index of Al_2O_3 used for the heat sink
film is about 1.7. Table 5 shows the evaluation

5 results. The disc of Example N was superior in each of
CNR and erasure rate compared to those of Example M1.
Also, the disc of Example N exhibited a low X-E level
that gives rise to no practical problem. Further, the
disc of Example N exhibited the most excellent

10 transmittance.

Table 5

	Example L	Example M1	Example M2	Example N
1st interference film	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm
Lower interface film	HfO$_2$ 1nm	HfO$_2$ 1nm	HfO$_2$ 1nm	HfO$_2$ 1nm
Recording film	GeSbTe 6nm	GeSbTeBi 6nm	GeSbTeSn 6nm	GeSbTeBi 6nm
Upper interface film	HfO$_2$ 1nm	HfO$_2$ 1nm	HfO$_2$ 1nm	HfO$_2$ 1nm
2nd interference film	SiO$_2$ 14nm	SiO$_2$ 14nm	SiO$_2$ 14nm	ZnS:SiO$_2$ 20nm
Semi-transparent reflecting film	Ag alloy 6nm	Ag alloy 6nm	Ag alloy 6nm	Ag alloy 6nm
Heat sink film	SiO$_2$ 30nm	SiO$_2$ 30nm	SiO$_2$ 30nm	Al$_2$O$_3$ 30nm
Rc	13	13.7	10.5	5.9
Ra	5.1	5.5	5	1.4
Average transmittance	45	46	47	50
bER (G)	$4.0*10^{-5}$	$9.8*10^{-6}$	$4.5*10^{-5}$	$5.1*10^{-6}$
bER (L)	$5.5*10^{-5}$	$2.3*10^{-5}$	$3.0*10^{-5}$	$2.1*10^{-5}$
CNR (G)	53	55.2	51.7	56.0
CNR (L)	52.3	54.1	52.6	54.1
Erasure rate (G)	-26.5	-29.7	-29.6	-31.9
Erasure rate (L)	-27	-28.2	-30.9	-31.5
X-E (G)	-0.2	-0.1	-0.3	-0.3
X-E (L)	-0.4	0	0	0

Comparative Examples L1 and L2 (Change in Material of Interface Film to GeN and Cr-O):

A disc similar to that of Example N was fabricated in which the material of the interface film was changed to GeN (Comparative Example L1), and another disc similar to that of Example N was fabricated in which the material of the interface film was changed to Cr-O (Comparative Example L2). Table 6 shows the evaluation results. The disc of each of Comparative Examples L1 and L2 was markedly inferior in bER compared to the disc of Example N. Judging from the results of the analog measurements, the reason why the poor bER was resulted in Example L1 or L2 is ascribed to the poor X-E value in the case of the GeN interface film, and to the poor CNR value in the case of the Cr-O interface film.

Incidentally, it is possible to improve either the CNR or the X-E to some extent by controlling the thickness of the interface film even in the case of using GeN or Si-N. However, it is impossible to improve both the CNR and the X-E simultaneously.

Comparative Example M (No Interface Film)

A disc (Comparative Example M) having the structure of $ZnS:SiO_2/GeSbTeBi/ZnS:SiO_2/Ag$ alloy/Al_2O_3 was fabricated, in which the interface films were omitted from the disc of Example N. Table 6 shows the evaluation results. In the optical disc of Comparative

Example M, it was impossible to measure bER. Also, the

disc of Comparative Example M was very poor in CNR,

which reflected the poor erasure rate in overwriting.

As a result, the disc of Comparative Example M was

5   substantially incapable of performing rewrite under the

evaluating conditions.

Table 6

	Comparative Example L1	Comparative Example L2	Comparative Example M
1st interference film	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm
Lower interface film	GeN 1nm	Cr-O 2nm	None
Recording film	GeSbTeBi 6nm	GeSbTeBi 6nm	GeSbTeBi 6nm
Upper interface film	GeN 1nm	Cr-O 2nm	None
2nd interference film	ZnS:SiO$_2$ 20nm	ZnS:SiO$_2$ 20nm	ZnS:SiO$_2$ 20nm
Semi-transparent reflecting film	Ag alloy 6nm	Ag alloy 6nm	Ag alloy 6nm
Heat sink film	Al$_2$O$_3$ 30nm	Al$_2$O$_3$ 30nm	Al$_2$O$_3$ 30nm
Rc	5.4	5.4	6.2
Ra	1.4	1.1	1.1
Average transmittance	49	50	50
bER (G)	$1.5*10^{-5}$	$2.2*10^{-3}$	Unmeasured
bER (L)	$3.1*10^{-4}$	$3.1*10^{-3}$	Unmeasured
CNR (G)	52.8	44.3	37.5
CNR (L)	52.1	41.9	36.5
Erasure rate (G)	-28.4	-24.4	-20.1
Erasure rate (L)	-26.5	-22.5	-21.9
X-E (G)	-3.7	-0.3	-0.1
X-E (L)	-1.5	0	0

Examples O1, O2 (Dependency on Thickness of Recording Film):

Phase-change optical recording discs differing from that of Example N in the thickness of the recording film were fabricated. In the disc of Example O1, the thickness of the recording film was decreased to 5 nm. In the disc of Example O2, the thickness of the recording film was increased to 8 nm. Table 7 shows the evaluation results. In the disc of Example O1, the reflectance difference between the crystalline phase and the amorphous phase was not sufficiently large, with the result that the disc was inferior in CNR compared to Example N. The disc of Example O2 was excellent in each of CNR and erasure rate. However, the disc of Example O2 was inferior in the average transmittance compared to Example N, with the result that it was difficult to write and read data in and out of the second information layer. Thus, it has been found that it is desirable for the recording film to have a thickness falling within a range of between 5 nm and 8 nm.

Examples P1 and P2 (Dependency on Thickness of Reflection Film):

Phase-change optical discs differing from that of Example N in the thickness of the reflection film were fabricated. In the disc of Example P1, the thickness of the reflection film was decreased to 5 nm. In the

disc of Example P2, the thickness of the reflection film was increased to 10 nm. Table 7 shows the evaluation results. The disc of Example P1 was inferior in CNR compared to Example N because the

5 cooling effect of the reflection film was weakened. The disc of Example P2 was excellent in each of CNR and erasure rate. However, the disc of Example P2 was inferior in the average transmittance compared to the disc of Example N, with the result that it was

10 difficult to write and read data in and out of the second information layer. Thus, it has been found that it is desirable for the reflection film to have a thickness falling within a range of between 5 nm and 10 nm.

Table 7

	Example O1	Example O2	Example P1	Example P2
1st interference film	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm
Lower interface film	HfO$_2$ 1nm	HfO$_2$ 1nm	HfO$_2$ 1nm	HfO$_2$ 1nm
Recording film	GeSbTeBi 5nm	GeSbTeBi 8nm	GeSbTeBi 6nm	GeSbTeBi 6nm
Upper interface film	HfO$_2$ 1nm	HfO$_2$ 1nm	HfO$_2$ 1nm	HfO$_2$ 1nm
2nd interference film	ZnS:SiO$_2$ 20nm	ZnS:SiO$_2$ 20nm	ZnS:SiO$_2$ 20nm	ZnS:SiO$_2$ 20nm
Semi-transparent reflecting film	Ag alloy 6nm	Ag alloy 6nm	Ag alloy 5nm	Ag alloy 10nm
Heat sink film	Al$_2$O$_3$ 30nm	Al$_2$O$_3$ 30nm	Al$_2$O$_3$ 30nm	Al$_2$O$_3$ 30nm
Rc	5.5	7.9	4.9	8.2
Ra	2.4	0.8	1.1	2.1
Average transmittance	52	42	52	41
bER (G)	$1.3*10^{-4}$	$6.3*10^{-6}$	$1.9*10^{-4}$	$9.6*10^{-6}$
bER (L)	$1.1*10^{-4}$	$7.8*10^{-6}$	$3.2*10^{-4}$	$5.2*10^{-6}$
CNR (G)	50.3	56.7	51.3	56.3
CNR (L)	51.2	55.8	50.3	57.2
Erasure rate (G)	-28.1	-33.2	-27.6	-27.8
Erasure rate (L)	-25.5	-35.1	-26.3	-29.1
X-E (G)	0	-0.7	0	-0.2
X-E (L)	0	-0.4	0	-0.3

Example Q (Combination of HfO_2 Interface Film and SiO_2 Heat Sink Film):

A phase-change optical disc (Example Q) having the structure of $ZnS:SiO_2/HfO_2/GeSbTeBi/HfO_2/ZnS:SiO_2/Ag$ alloy/SiO_2 was fabricated. The composition of GeSbTeBi was equal to that for the disc of Example M1. Table 8 shows the evaluation results. The characteristics of the disc of Example Q including CNR, erasure rate and X-E were found to be on the levels free from the practical problem.

Example R (Combination of CeO_2 Interface Film and Al_2O_3 Heat Sink Film):

A phase-change optical disc (Example R) was fabricated using CeO_2 for the interface film and Al_2O_3 for the heat sink film, the disc having the structure of $ZnS:SiO_2/CeO_2/GeSbTeBi/CeO_2/SiO_2/Ag$ alloy/Al_2O_3. The composition of GeSbTeBi was equal to that for the disc of Example M1. The heat conductivity of CeO_2 is 15 W/mK and the heat conductivity of Al_2O_3 is 30 W/mK. Table 8 shows the evaluation results. Since the heat conductivity of the Al_2O_3 heat sink film is higher than that of the CeO_2 interface film, the disc of Example R exhibits a high CNR and a high erasure rate so as to attain low cross-erase.

Example S (Disc Having Interface Film on One Surface of Recording Film):

A phase-change optical disc (Example S) having the

structure of $ZnS:SiO_2/GeSbTeBi/CeO_2/ZnS:SiO_2/Ag$ alloy/Al_2O_3 was fabricated, in which the lower interface film was not formed. The composition of GeSbTeBi was equal to that for the disc of Example M1.

5   Table 8 shows the evaluation results. The disc of Example S was high in each of CNR and erasure rate and low in cross-erase.

Example T (Omission of Second Interference Film):

A phase-change optical disc (Example T) having the

10   structure of $ZnS:SiO_2/GeSbTeBi/HfO_2/Ag$ alloy/Al_2O_3 was fabricated, in which the lower interface film was omitted and an upper interface film was substituted for the second interference film. The composition of GeSbTeBi was equal to that for the disc of Example M1.

15   Table 8 shows the evaluation results. The disc of Example T was high in each of CNR and erasure rate and low in cross-erase.

Table 8

	Example Q	Example R	Example S	Example T
1st interference film	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 40nm
Lower interface film	HfO$_2$ 1nm	CeO$_2$ 3nm	None	None
Recording film	GeSbTeBi 6nm	GeSbTeBi 6nm	GeSbTeBi 6nm	GeSbTeBi 6nm
Upper interface film	HfO$_2$ 1nm	CeO$_2$ 3nm	CeO$_2$ 3nm	HfO$_2$ 10nm
2nd interference film	ZnS:SiO$_2$ 20nm	SiO$_2$ 14nm	ZnS:SiO$_2$ 18nm	None
Semi-transparent reflecting film	Ag alloy 6nm	Ag alloy 6nm	Ag alloy 6nm	Ag alloy 8nm
Heat sink film	SiO$_2$ 30nm	Al$_2$O$_3$ 30nm	Al$_2$O$_3$ 30nm	Al$_2$O$_3$ 30nm
Rc	6.1	13.2	6.7	6.1
Ra	1.2	4.6	1.3	1.1
Average transmittance	50	46	49	50
bER (G)	$1.3*10^{-5}$	$7.3*10^{-5}$	$9.5*10^{-6}$	$8.8*10^{-5}$
bER (L)	$7.3*10^{-5}$	$7.8*10^{-5}$	$1.0*10^{-5}$	$1.8*10^{-4}$
CNR (G)	54.0	52.3	55.6	53.2
CNR (L)	52.0	52.1	54.4	51.5
Erasure rate (G)	-33.4	-33.1	-28.7	-30.1
Erasure rate (L)	-32.0	-31.6	-27.7	-29.8
X-E (G)	-0.1	-0.4	0	0.1
X-E (L)	-0.2	0	0	0.3

Comparative Example N (Heat Sink Film having Low Heat conductivity):

A disc (Comparative Example N) having the structure of $ZnS:SiO_2/CeO_2/GeSbTeBi/CeO_2/SiO_2/Ag$ alloy/SiO_2, in which the material of the heat sink film in the disc of Example R was changed to SiO_2. Table 9 shows the evaluation results. The disc of Comparative Example N shows high cross-erase. The reason of the high cross-erase is attributed to the fact that the heat conductivity (1.3 W/mK) of the SiO_2 heat sink film is markedly lower than the heat conductivity (15 W/mK) of the CeO_2 interface film.

Comparative Example O (Heat Sink Film having Excessively High Heat conductivity):

A disc (Comparative Example O) having the structure of $ZnS:SiO_2/HfO_2/GeSbTeBi/HfO_2/SiO_2/Ag$ alloy/AlN was fabricated, in which the material of the heat sink film in the disc of Example M1 was changed to AlN. Table 9 shows the evaluation results. The disc of Comparative Example O was incapable of obtaining a sufficient CNR even under the condition of write power of 11 mW that was the maximum for the laser mounted to the evaluating apparatus. This is because excessively high heat conductivity (270 W/mK) of AlN brings about degraded recording sensitivity.

Example U. (Change in Composition of Interface Film):

A phase-change optical disc (Example U) having a stacked structure as shown in Table 9 was fabricated. In this case, HfO_2-SiO_2 having a molar ratio of 60 : 40 was used in place of HfO_2 for the interface film. Table 9 shows the evaluation results.

Comparative Example P (Change in Composition of Interface Film):

A phase-change optical disc (Comparative Example P) having a stacked structure as shown in Table 9 was fabricated. In this case, HfO_2-SiO_2 having a molar ratio of 40 : 60 was used in place of HfO_2 for the interface film. Table 9 shows the evaluation results.

It has been found that, even in the case of using an interface film formed of $(HfO_2)_{60}(SiO_2)_{40}$ as in Example U, the bER in the order of 10^{-5} is maintained and the erasure rate is sufficiently high, although these values are inferior than those for Example L. On the other hand, in the case of using an interface film formed of $(HfO_2)_{40}(SiO_2)_{60}$ as in Comparative Example P, bER cannot be measured and also CNR is very poor. It can be judged from these results that, in the case where an additive material (for example, SiO_2) other than HfO_2, CeO_2, TiO_2 and ZrO_2 is added to the interface film, the amount of the additive material should preferably be set to 50 % or less.

Table 9

	Comparative Example N	Comparative Example O	Example U	Comparative Example P
1st interference film	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm	ZnS:SiO$_2$ 50nm
Lower interface film	CeO$_2$ 3nm	HfO$_2$ 3nm	(HfO$_2$)60(SiO$_2$)40 1nm	(HfO$_2$)40(SiO$_2$)60 1nm
Recording film	GeSbTeBi 6nm	GeSbTeBi 6nm	GeSbTeBi 6nm	GeSbTeBi 6nm
Upper interface film	CeO$_2$ 3nm	HfO$_2$ 3nm	(HfO$_2$)60(SiO$_2$)40 1nm	(HfO$_2$)40(SiO$_2$)60 1nm
2nd interference film	SiO$_2$ 14nm	SiO$_2$ 14nm	SiO$_2$ 14nm	SiO$_2$ 14nm
Semi-transparent reflecting film	Ag alloy 6nm	Ag alloy 6nm	Ag alloy 6nm	Ag alloy 6nm
Heat sink film	SiO$_2$ 30nm	AlN 30nm	SiO$_2$ 30nm	SiO$_2$ 30nm
Rc	13.2	15.6	12.8	12.2
Ra	5	4.9	4.8	4.4
Average transmittance	46	45	46	45
bER (G)	$1.6*10^{-4}$	Unmeasured	$9.5*10^{-5}$	Unmeasured
bER (L)	$1.4*10^{-4}$	Unmeasured	$8.9*10^{-5}$	Unmeasured
CNR (G)	52.9	30.4	52.2	38.2
CNR (L)	51.2	28.3	52.4	35.5
Erasure rate (G)	-32.4	-15.5	-24.3	-18.5
Erasure rate (L)	-30	-14.1	-25.7	-16.2
X-E (G)	-3	0	-0.2	0
X-E (L)	0	0	-0.1	0

As described above, the material of the interface film in contact with the recording film according to the present invention brings about the effect of improving the crystallization speed. In the case where the crystallization speed is excessively high, for example, the interface film may contain a compound such as an oxide other than hafnium oxide, cerium oxide, titanium oxide and zirconium oxide, a nitride, a carbide and a sulfide, or another element. In particular, the interface film greatly affects not only the crystallization speed but also temperature hysteresis of the recording film. It follows that it is desirable to add another compound or element to the interface film for controlling the heat conductivity. The particular case is not deviated from the subject matter of the present invention.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the present invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.